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Autonomous Nested Search for Hydrothermal Venting

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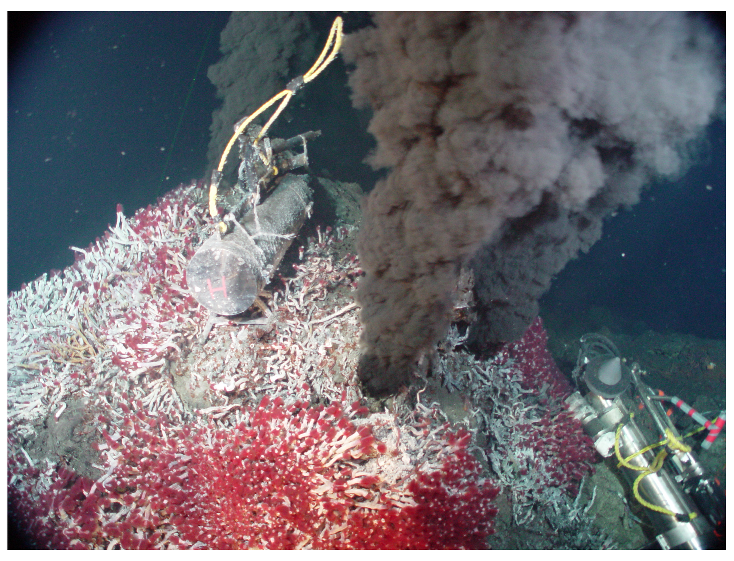
Poster #17

Image Credit: Marcel Nicolaus, AWI

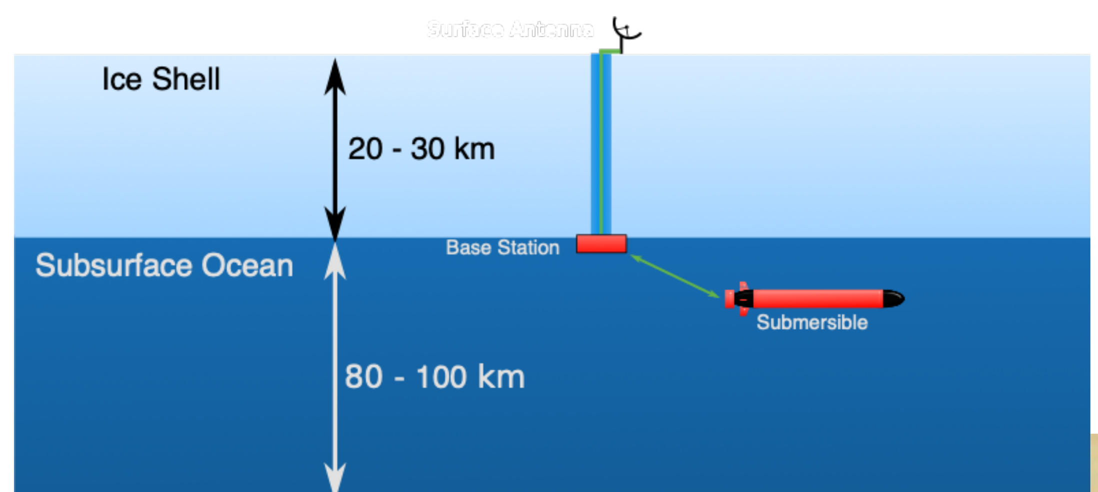


Credit: IFE, URI-IAO, UW, Lost City Science Party; NOAA/OAR/OER; The Lost City 2005 Expedition

Motivation

- 8+ bodies in the Solar System are thought to harbor sub-surface liquid oceans, including Europa and Enceladus
- Earth-based hydrothermal vents harbor unique life and are potentially crucial to the origin of life
- Potential hydrothermal venting on Europa
- Evidence for hydrothermal venting on Enceladus [4,5]

Problem Definition



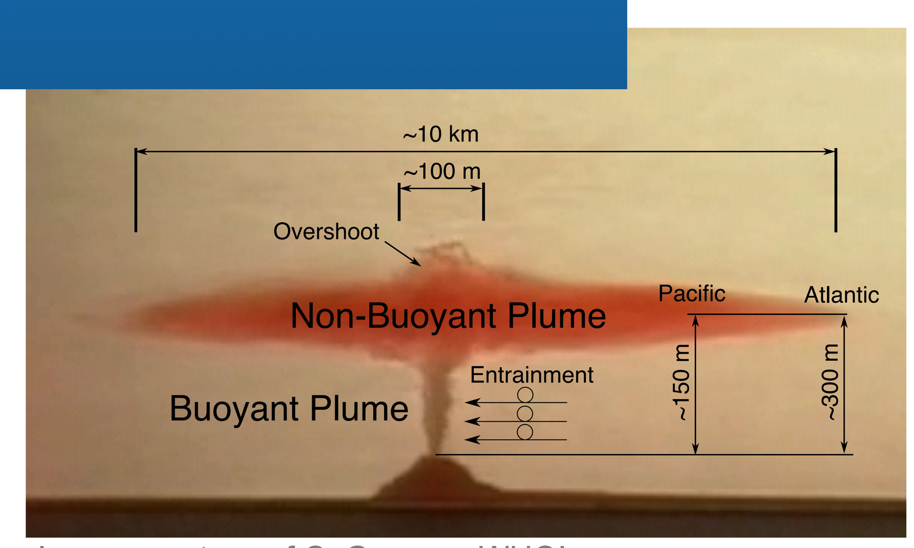


Image courtesy of C. German, WHOI

Ocean Worlds Submersible

- Single under-ice base station provides communication to Earth
- Travel 100s of km from base station
- Limited communication with Earth due to orbital occlusions and underwater acoustic communication range
- Fully autonomous operations required for weeks or months at a time
- **Goal: Autonomously detect, locate, and sample hydrothermal venting**

Hydrothermal Plumes

- Chemically altered seawater detectible through temperature, redox, and optical backscatter
- Hot, low density plume fluid exits vent forming buoyant plume [2]
- Density equilibrium reached and non-buoyant plume formed [2]
- Source vent can be tracked using the hydrothermal plume

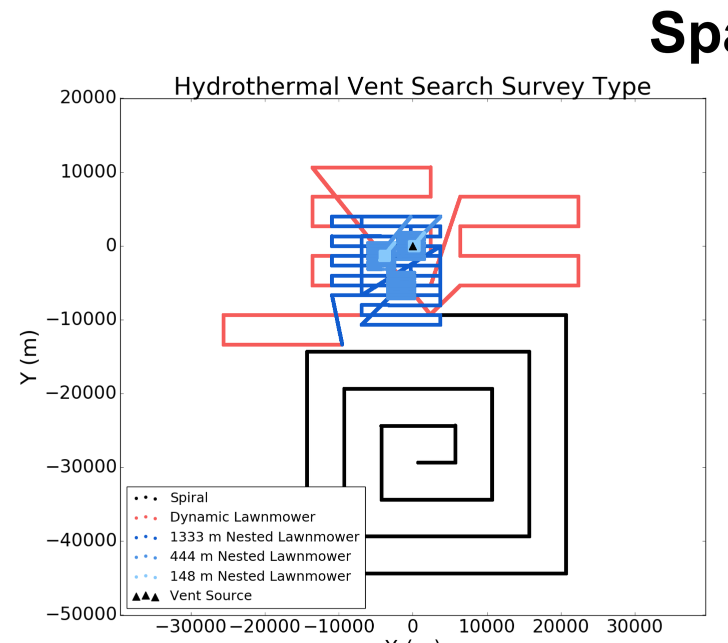
Objectives

- Perform high resolution survey of region immediately surrounding hydrothermal venting
- Autonomous adaptation of proven human-in-the-loop search method [3]
- Must maintain robustness to local maxima and small-scale turbulence

Approach

- Progressively higher resolution nested surveys to pinpoint maximum vent fluid concentration
- Three Search Phases:
  - Initial spiral survey
  - Dynamic lawnmowers
  - Nested lawnmowers

Spatial Nested Search

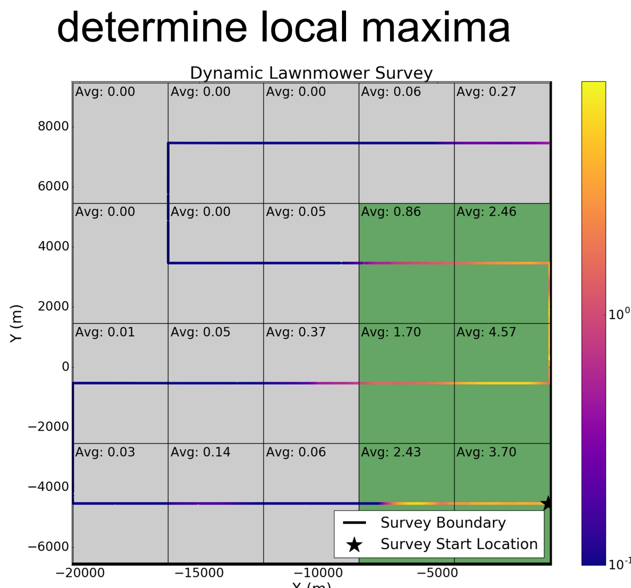


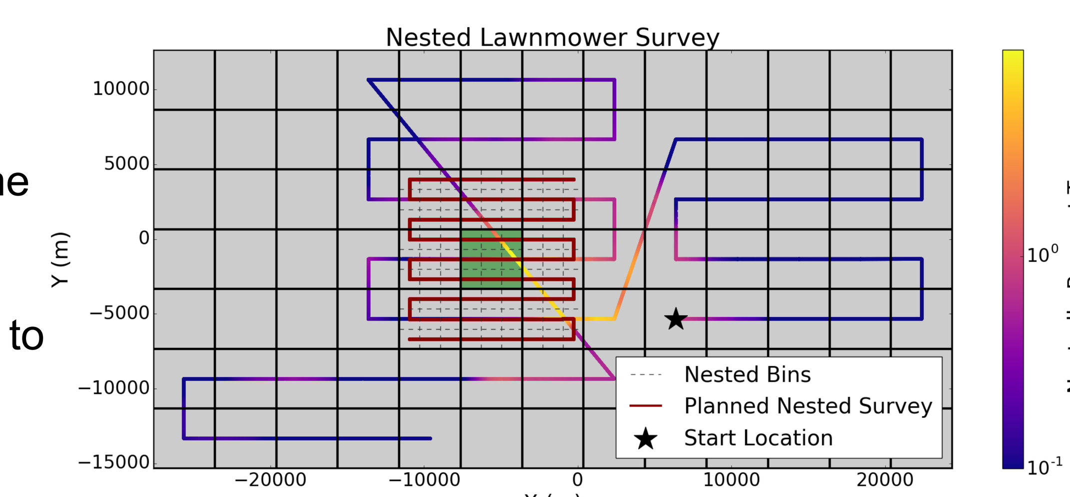
Spiral Survey

- Spiral centered at the base station
- Yo-Yo pattern from surface to seafloor to locate non-buoyant plume
- Terminates on first contact with plume above specified threshold

Dynamic Lawnmower

- Performed at first contact with plume
- Variable size lawnmower survey to determine the extent of the plume
- Data binned at resolution of survey to determine local maxima





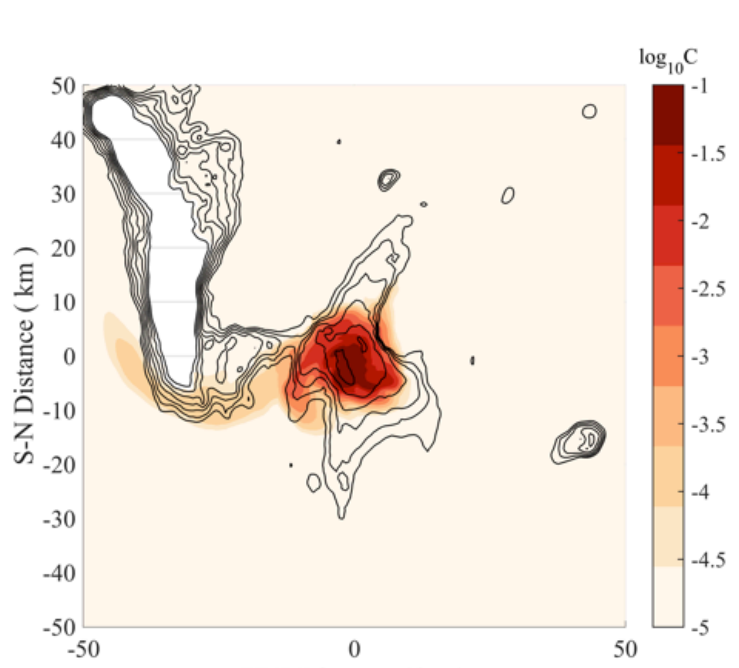
Nested Lawnmowers

- Perform recursively higher resolution surveys of previously searched regions
- Each survey encompasses local maxima and surrounding bins
- Prioritized based on average plume strength of bin and survey resolution

Simulation

Hydrothermal Venting Model

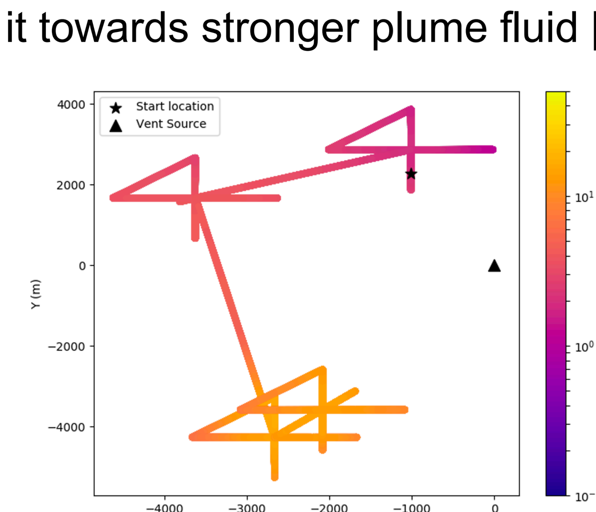
- FVCOM based circulation and hydrothermal plume model of Axial Seamount
- 1 GW heat source in the Axial caldera
- Initial forcing constructed with HYCOM and OSU Tidal Inversion models
- 300x300 km, 60 day simulation
- Model variables: temperature, salinity, currents, passive tracer



Baseline Search Methods

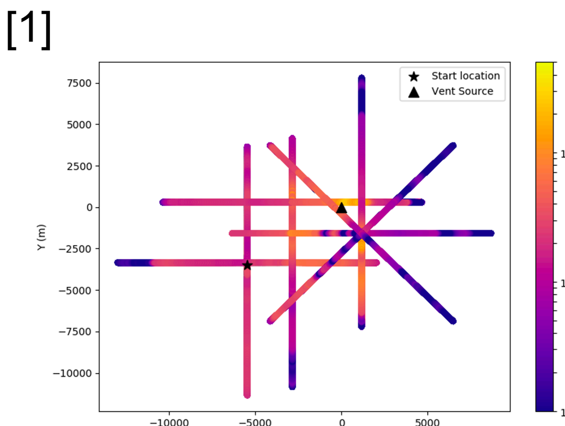
Gradient Ascent

- Determine the plume gradient at a location and follow it towards stronger plume fluid [1]



Greedy Transect

- Direction Set: Perform fixed pattern searching for increased plume strength. Repeat this pattern at new maxima until no new max plume values are seen [1]



Results

Example Nested Bin Search Result

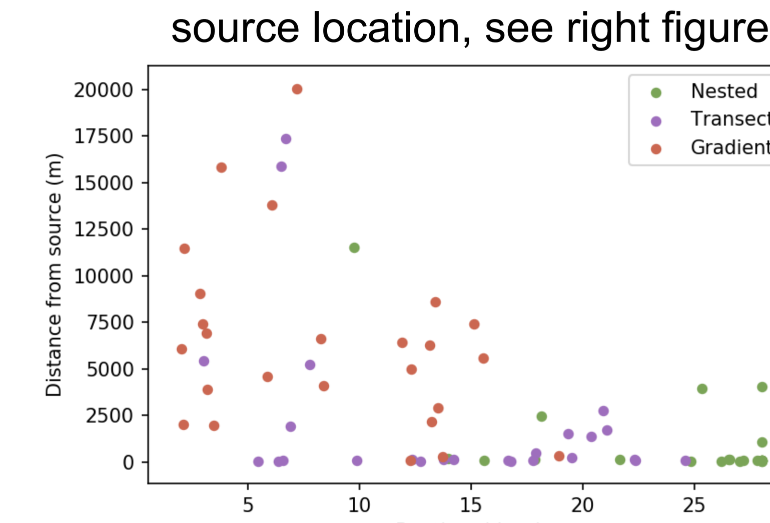
Simulated Results

- 25 simulation runs per algorithm with starting x,y uniformly distributed from [-30,30] km
- Nested Search better estimates the vent location over baseline methods, however with longer search times. See table and left figure below.

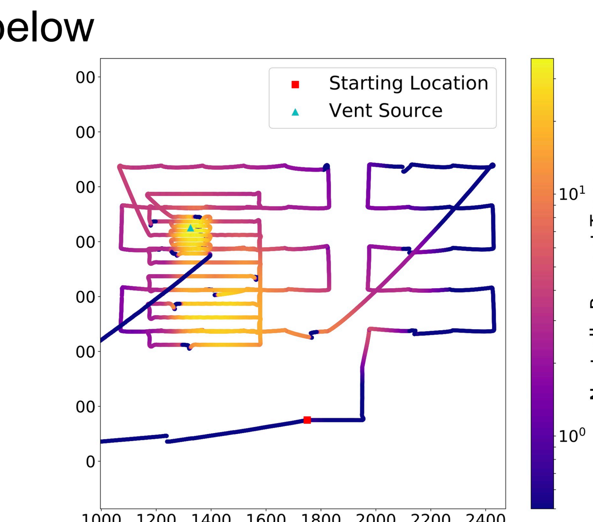
Algorithm	Nested Search	Gradient Ascent	Greedy Transect
Success Rate (< 200m of ground truth)	80%	56%	4%

Deployment

- Deployed Nested Search algorithm onboard an Iver AUV in Chesapeake Bay with NRL in June 2019
- Successfully demonstrated the vehicle locating the simulated vent source location, see right figure below



Simulation Results: Distance from True Vent Location Vs. Time



Demonstration onboard Iver AUV

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